A Report on Attribution of Annual Mean Atmospheric Anomalies for 2003

A Collaborative Effort Between

Climate Diagnostics Center

Climate Prediction Center

Center for Ocean-Land-Atmosphere

Geophysical Fluid Dynamics Laboratory

International Research Institute

NASA/Global Modeling and Assimilation Office

and

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Support Provided by

Office of Global Programs

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Summary

An attribution of yearly mean observed atmospheric anomalies for 2003 is performed in terms of possible influence from the observed sea surface temperature anomalies. The approach is to compare the atmospheric signal forced by the observed SST anomalies. The atmospheric signal was inferred from a suite of atmospheric general circulation model simulations, and was compared with the observed atmospheric anomalies. A general agreement between the atmospheric response to SSTs and the observed anomalies implies that the annual mean observed atmospheric anomalies could be attributed to the observed sea surface temperature forcing. This is particularly true for the observed land surface temperature anomalies that were above normal throughout the year, a behavior also simulated by AGCMs forced with the observed SSTs.

1. Annual mean atmospheric anomalies for 2003:

In this report, an attempt is made to understand the causes for the annual mean atmospheric anomalies for the year 2003. Our main focus is to seek attribution of annual mean land surface temperature, annual mean rainfall, and annual mean 200-mb heights. While understanding causality of the first two variables, i.e., land surface temperature and rainfall, is of great societal interest, the analysis of 200-mb heights highlights the global influence of tropical sea surface temperatures (SSTs) that are hypothesized as one possible cause for the observed atmospheric anomalies.

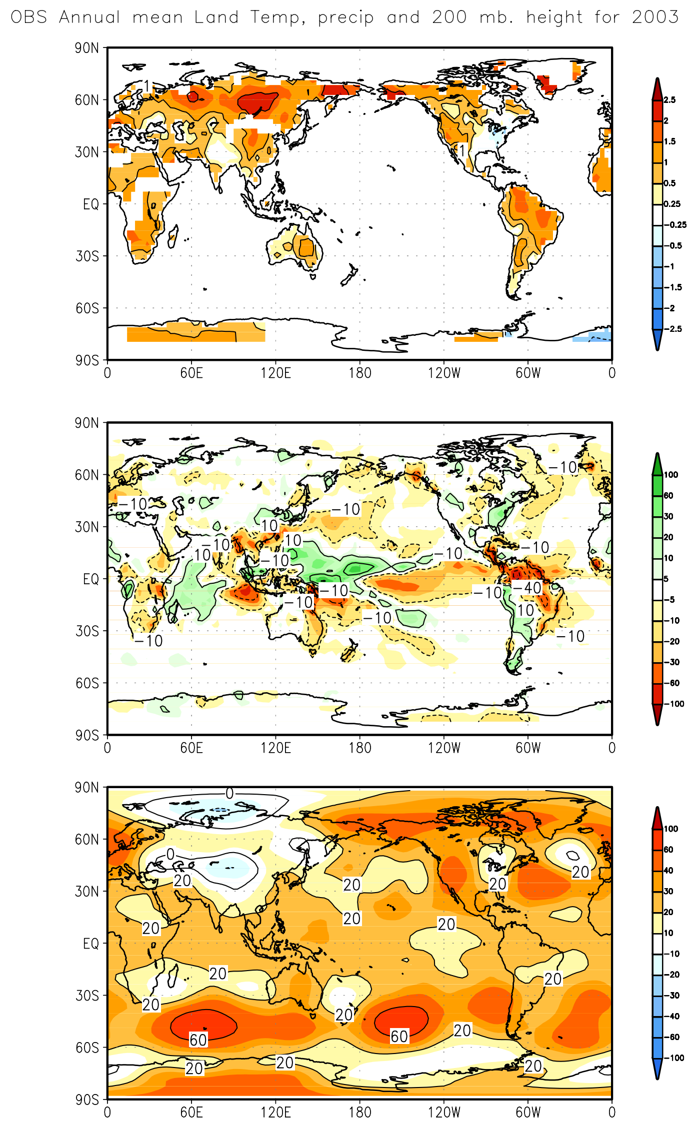

Fig. 1. 2003 annual mean observed anomalies for land surface temperature (top panel, Deg C); rainfall (middle panel, mm/month); and 200-mb heights (bottom panel, meters). Land surface temperature and 200-mb height anomalies are computed relative to 1950-2000 mean. Rainfall anomalies are computed relative to 1970-2000 mean. Same climatological base periods are used for the model simulations.

Shown in Fig. 1 are the observed land surface temperature, rainfall, and 200-mb height anomalies averaged for the calendar year 2003. Annual mean land surface temperatures were above normal almost all over the globe, and were consistent with the above normal 200-mb height anomalies that were also above normal. On the other hand, rainfall anomalies had more complex spatial structure with positive rainfall anomalies in the equatorial region west of the date line, and negative rainfall anomalies to the east. For the tropical landmasses, for example, South America, Africa etc., rainfall anomalies were below normal. Further, positive rainfall anomalies occurred over much of the Indian Oceans.

Were the annual mean land surface temperature anomalies in Fig. 1 evenly distributed throughout the year, or were they an artifact of extreme warm anomalies for some selected months within the year? The time-series of globally averaged land surface temperatures for each month shown in Fig. 2 demonstrates that globally averaged land surface temperature was above normal throughout the year, and therefore, warmer anomaly for each month contributed to the positive annual mean anomaly.

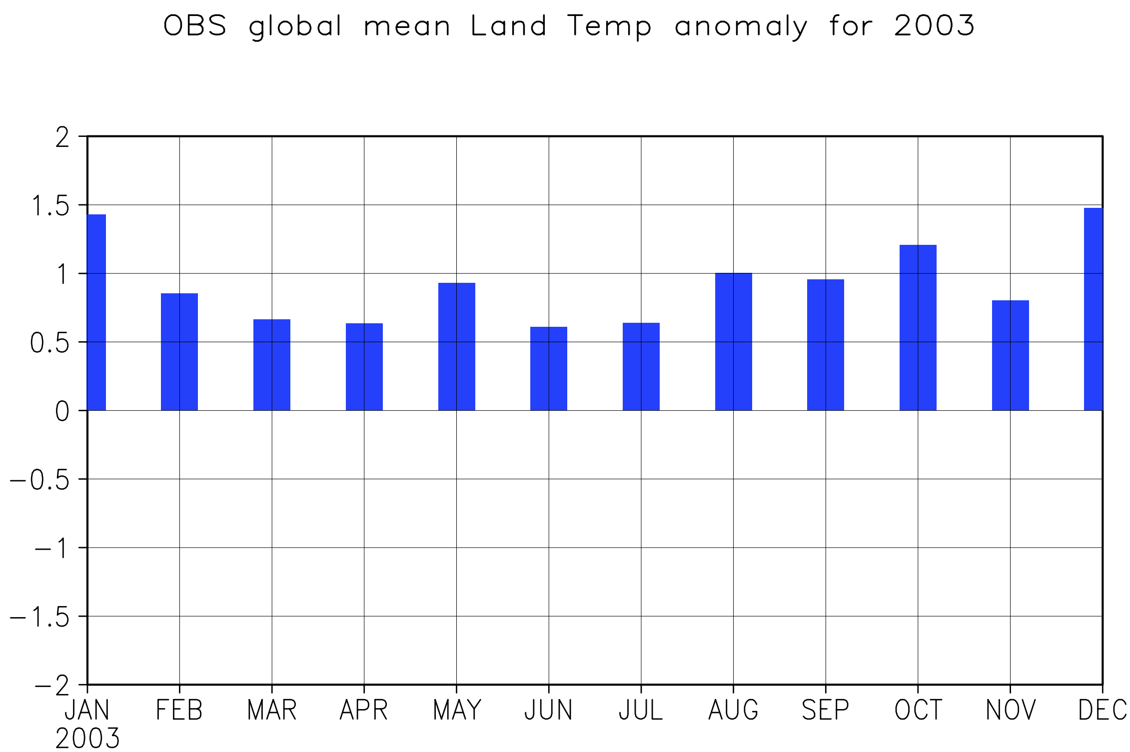

Fig. 2. Monthly mean time-series of globally averaged (Deg C) observed land surface temperature anomaly.

A question is posed if some forcing external to the atmosphere caused the observed anomalies in Fig. 1 or they were manifestation of atmospheric internal variability. One possible candidate for the external forcing responsible for atmospheric anomalies in Fig. 1 could be the observed global SST anomalies (Fig. 3). That it could be the case is hinted at by the fact that on average, annual mean tropical SST anomalies were above normal throughout the equatorial latitudes, except near the western coast of South America, and could possibly lead to above normal 200-mb heights and land surface temperatures.

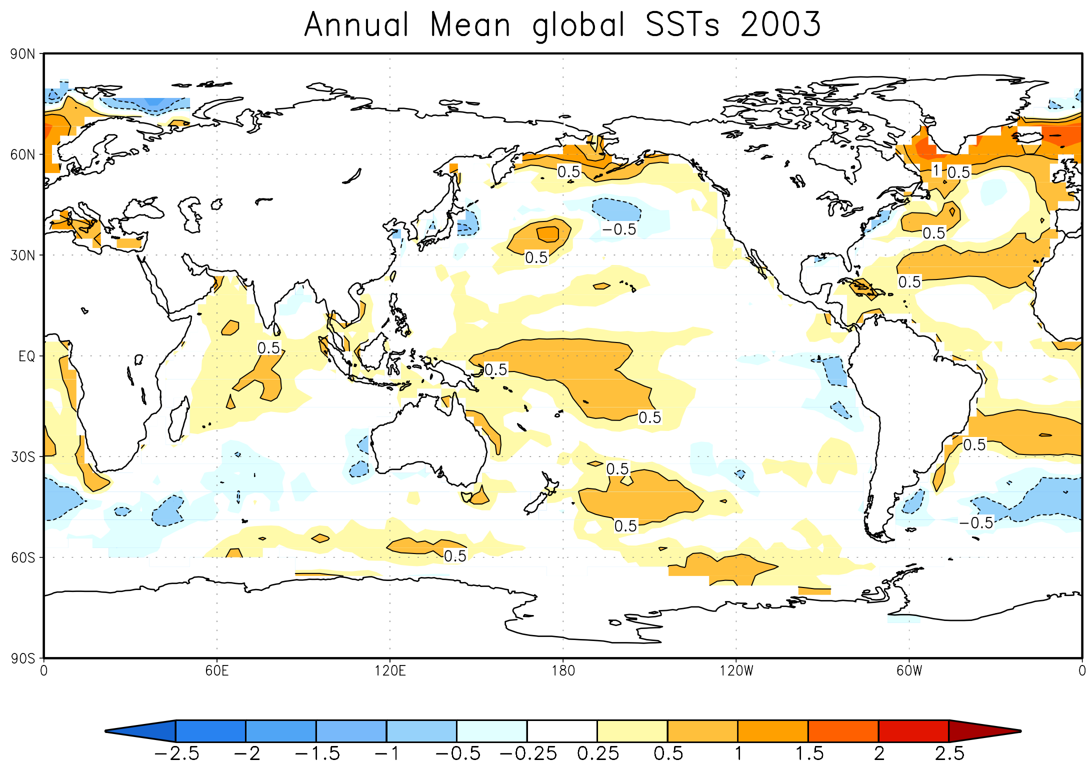

Fig. 3. 2003 annual mean sea surface temperature anomaly (Deg C).

2. An approach for the attribution of atmospheric climate anomalies:

In an attempt to attribute observed anomalies to the observed SST forcing, one key aspect is to know to what extent atmospheric anomalies were consistent with the observed SSTs. In other words we seek to document what the *atmospheric response* to observed SST forcing was, and further, were the observed atmospheric anomalies themselves consistent with the atmospheric response. For if they were, it is likely that the observed atmospheric anomalies could be attributed to the observed SST anomalies. However, if the atmospheric response to SST and the observed atmospheric anomalies had large differences, it implies that either the observed anomalies were due to atmospheric internal variability or were caused by some forcing other than SST external to the atmosphere.

The approach for documenting atmospheric response to observed SSTs is based on atmospheric general circulation model (AGCM) simulations forced with observed SSTs. AGCM simulations were part of the "Seasonal Diagnostics Consortium" activity funded by NOAA's Office of Global Programs (Barnston et al. 2004). As a part of this coordinated activity, once a month several AGCM models are updated forced by the observed SSTs (the so called AMIP-style simulations). A list of AGCM and simulation details is given in Table 1. All participating AGCMs have an ensemble of simulations, and from the ensemble mean anomalies atmospheric response to observed SSTs is derived. As inferences about atmospheric response could be easily influenced by the AGCM biases, agreement between atmospheric responses obtained from different AGCMs is used as a necessary criteria to enhance our confidence in the realism of atmospheric response to SSTs.

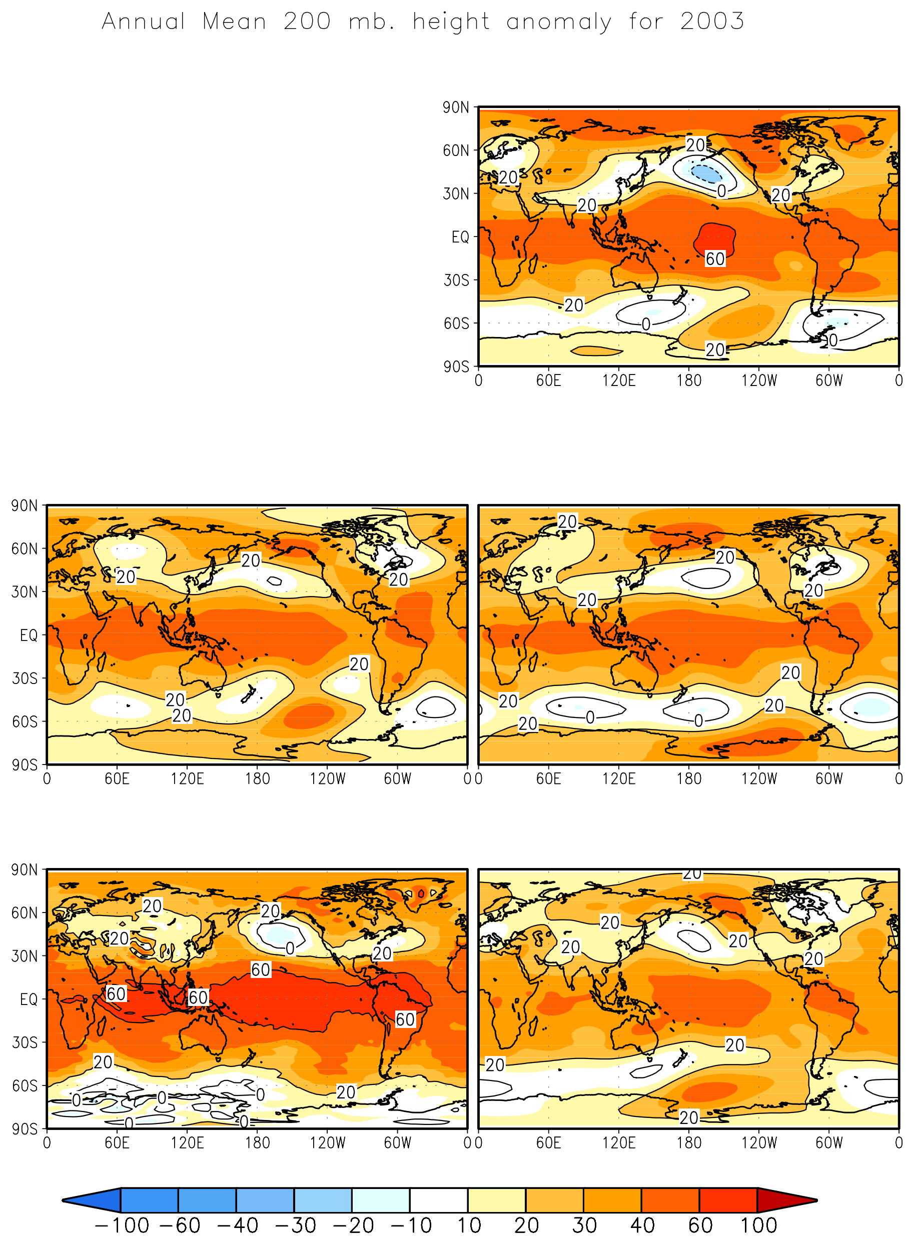

Fig. 4. 200-mb height anomalies (meters) simulated by five different AGCMs forced with the observed SSTs for the year 2003. Each AGCM has an ensemble of simulations and ensemble mean anomaly is shown. The ensemble mean anomaly also represents the atmospheric response to the SST forcing.

3. Discussion of atmospheric response to observed SSTs inferred from AGCM simulations:

For the annual mean of 2003, AGCM simulated atmospheric response to the observed SSTs for five different AGCMs is shown in Fig. 4. All five AGCMs have above normal tropical heights that are flanked by lower values (and occasionally, below normal heights) in the extratropical latitudes around 45^o N. Positive tropical heights are consistent with the above normal tropical SSTs. As 200-mb height response to imposed SST forcing in 5 AGCMs is quite similar, it provides confidence in the realism of the atmospheric response.

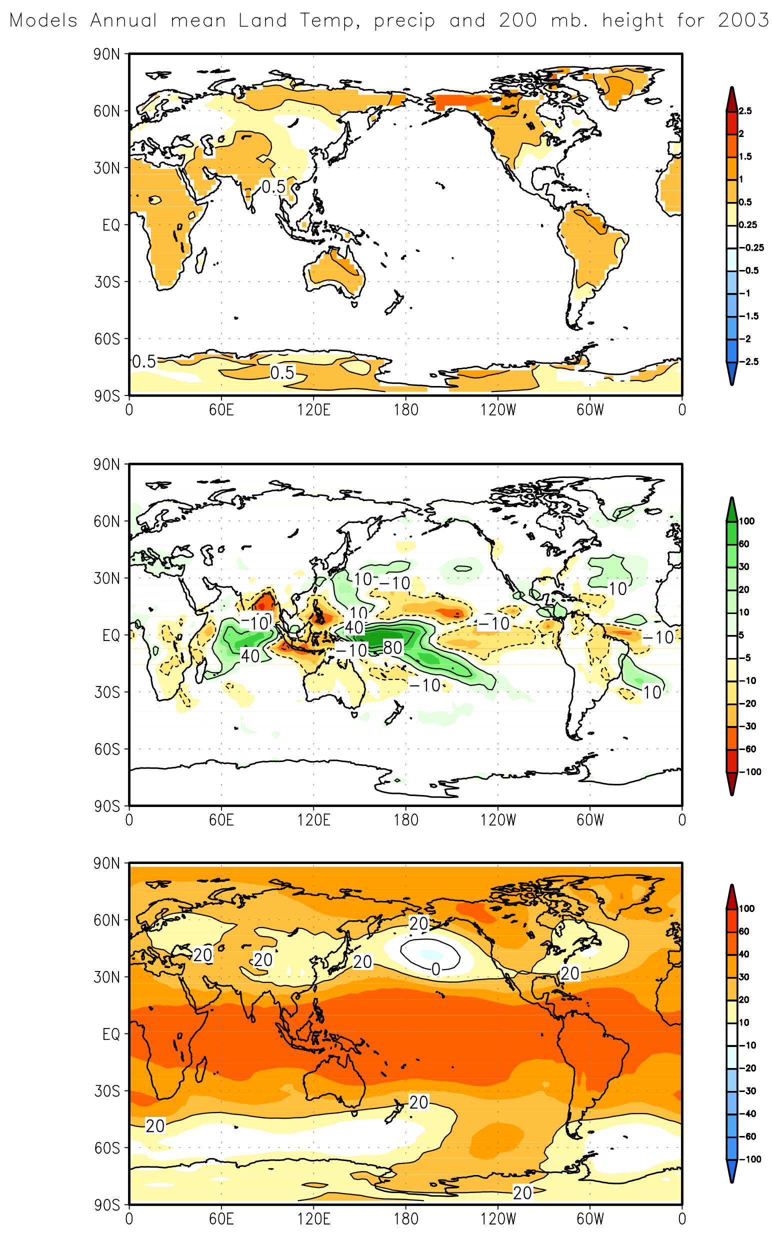

Fig. 5. 2003 annual mean AGCM simulated ensemble mean anomalies for land surface temperature (top panel, Deg C); rainfall (middle panel, mm/month); and 200-mb heights (bottom panel, meters). Anomalies from all the AGCM simulations are added to create the ensemble mean.

Consistency among 200-mb height response from different AGCMs is quantified based on spatial anomaly correlation over the globe, tropics, and over the Pacific North American (PNA) region. These correlations are shown in Table 2 and are higher than 0.85 indicating that the spatial pattern of atmospheric response to SSTs in different AGCMs was quite similar.

The annual mean AGCM response for land surface temperature, rainfall, and 200-mb height anomalies averaged over all 81 AGCM simulations is shown in Fig. 5. Similar to the observed land surface temperatures (see Fig. 1), AGCM simulations were also above normal. Similarly, the AGCM simulated 200-mb height response was also above normal over almost the entire globe. For the annual mean rainfall, above normal rainfall anomalies existed in the equatorial latitude west of the date line and were coincident with the above normal SSTs over that region (Fig. 3). Further, similar to the observed rainfall anomalies, AGCM rainfall response was for a below normal rainfall to the east of the date line, and also over the tropical land masses. Over the Indian Ocean, AGCM's rainfall response was for positive rainfall anomalies.

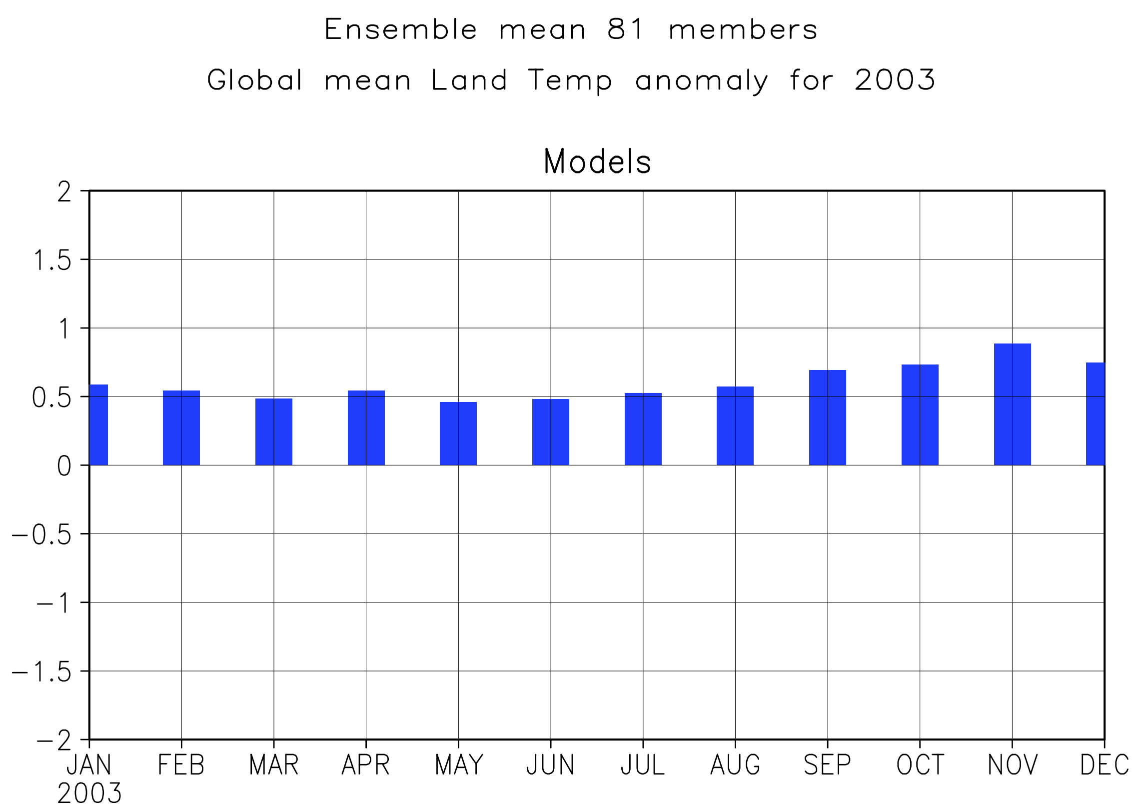

Fig. 6. Monthly mean time-series of globally averaged land surface temperature anomaly (Deg C) simulated by AGCMs.

Shown in Fig. 6 is the monthly evolution of globally averaged land surface temperature anomaly in Fig. 5, and indicates that similar to the observed anomalies (Fig. 2), AGCM simulated anomalies were also above normal for each month in the calendar year.

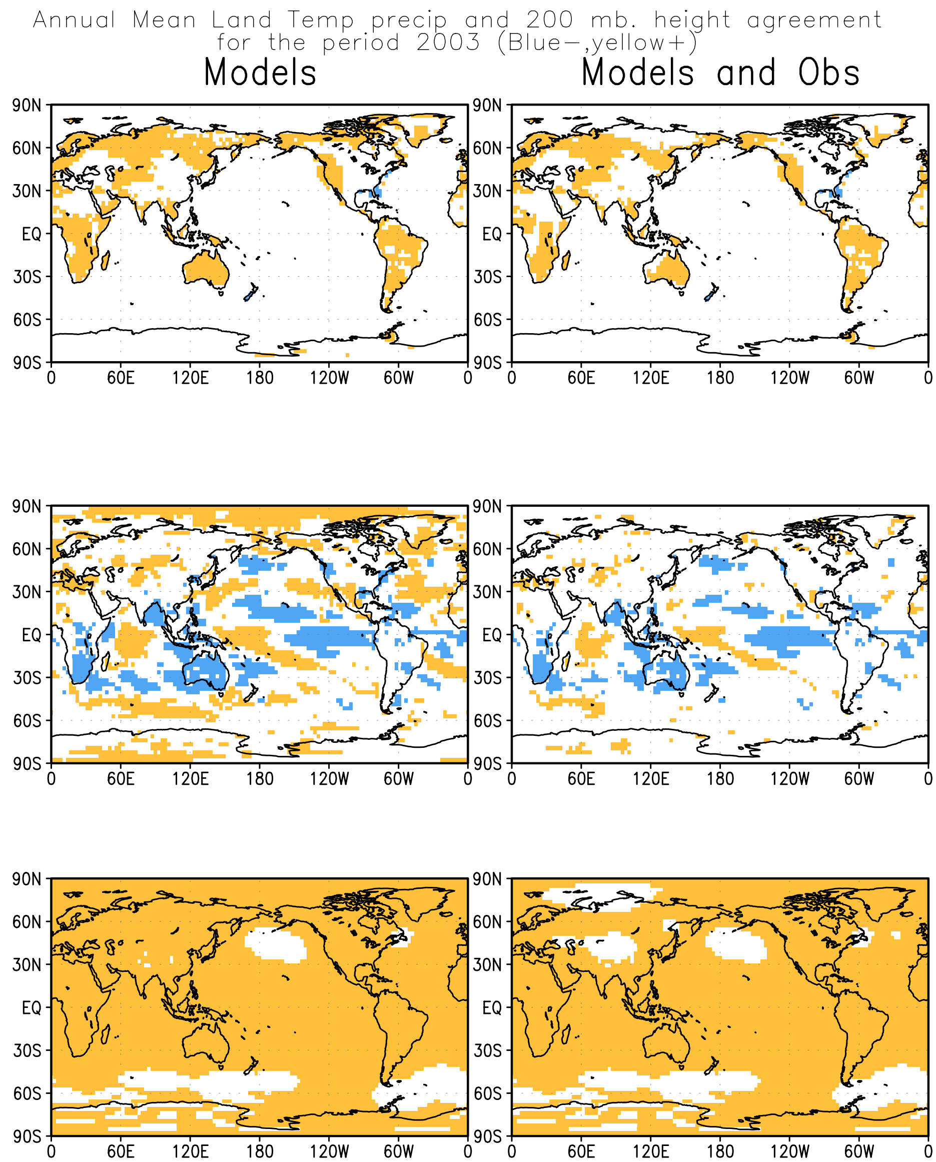

Fig. 7. Agreements plots between ensemble mean anomalies simulated by five different AGCMs (left panels). Regions where anomalies from all five models agree in sign are shaded yellow if anomalies were above normal or blue if anomalies were below normal. Agreement plots when observed anomalies are also included are on the right. Top row if for the land surface temperature, middle row is for rainfall, and bottom row is for 200-mb heights.

4. Comparison of AGCM's atmospheric response to the observed anomalies:

In this section we further compare the annual mean observed anomalies with the atmospheric response to the observed SSTs. Apart from a visual comparison discussed in the previous section, a spatial distribution of geographical locations where the observed anomalies and the atmospheric responses obtained from five different AGCMs have the same sign, is plotted. Such agreement plots for land surface temperatures, rainfall, and 200-mb height anomalies are shown in Fig. 7**.** Plots in the bottom panel depict the regions where the sign of atmospheric responses from all five AGCMs agree, while plots in the upper panel are for the agreement when observed anomalies are also included. For all three fields, at the grid points where observed as well as ensemble mean atmospheric anomalies were all above (below) normal are shaded in yellow (blue).

The largest agreement is between the 200-mb observed and AGCM simulated heights, and this agreement occurs almost over the entire globe, i.e., the sign of observed height anomalies and atmospheric responses from five different AGCMs agree in their sign. For the surface temperature over land, similar agreement is found. For example, sign of the observed surface temperature anomalies agrees with the AGCM responses over the tropical landmasses. Similar agreement is found over the northwestern North America.

A possible pathway for the observed SST anomalies to communicate their influence to the global atmospheric anomalies is via rainfall anomalies over the oceans, and particularly over the tropical oceans. An agreement plot for the rainfall anomalies in the tropical latitudes does indicate that the regions of positive and negative rainfall anomalies do agree over a wide spatial area.

5. Attribution

Our present approach for attribution of the climate anomalies to SSTs is based on the following: (1) For the observed SSTs we first infer the atmospheric response. In the present case this inference is based on an ensemble of AGCM simulations, and the ensemble mean anomaly is the atmospheric response to SSTs. In order that inferences are not influenced by the biases in AGCMs, it is critical that this analysis is based on ensemble means from several AGCMs. Following this multi-model approach for obtaining atmospheric signals to SST forcing, Figs. 4-5 provide us the necessary information. (2) On an individual realization basis, observed anomalies are a sum of atmospheric signal and the atmospheric internal variability, and there is no a priori constraint that the observed atmospheric anomalies should be similar to the atmospheric response. However, if they do, it is likely that it is because of the influence of the SST forcing. On the other hand, if the observed anomalies have little resemblance with the atmospheric signal, it is likely that the observed atmospheric anomalies had a large contribution from the atmospheric internal variability.

Following the above paradigm for attribution of atmospheric climate anomalies to SST forcing, analysis indicates that the observed atmospheric anomalies may have been largely consistent with the observed SST forcing. One striking example is the evolution of global mean land surface temperature anomalies that were above normal for the observations. Above normal anomalies were also simulated by the AGCMs forced with the observed SSTs.

6. Final comments

(a) The results analyzed here focus on the influence of the global oceans on the atmospheric climate variability. Given further computing resources, AGCM simulations could be easily performed to understand the atmospheric response to different oceans basins. An additional point to note is that the AGCM simulations only include observed SST forcing, and no information about the time evolution of other external forcing is used. On the other hand, time evolution of SSTs themselves may implicitly incorporate influence of changes in other external forcings.

(b) This was our first attempt to attribute atmospheric climate variability on a near real-time basis, and we foresee that this activity will expand further to include seasonal time-scales and other atmospheric variables.

(c) It is also not clear why the observed heights in the tropical latitudes are so much lower than what is simulated by the AGCMs as a response to SSTs. Is it an artifact of reanalysis from which the 200-mb heights are obtained needs to be investigated further.

(d) For this approach for attribution to succeed, multi-model AGCM simulations are the most critical aspect. At present this activity is supported by OGP and is distributed across different participating institutions. We hope that support for this activity will continue, and that multi-model AGCM simulations can be formalized as a NOAA-wide computing resource. Multi-model AGCM simulations will also have applications for other research interests.

(e) We also foresee attribution activity to link with the potential predictability of seasonal climate anomalies and will provide us with some understanding on the variability in skill of operational seasonal predictions. A summary of the skill for the operational forecasts, and their comparison with experimental seasonal forecasts, has already been done by the Climate Prediction Center, and we envision of linking it with the attribution activity.

(f) Web-sites and documents related to attribution and assessments of seasonal forecast activity:

Comparison of operational and experimental seasonal forecasts:

http://wesley.ncep.noaa.gov/verf/90day_nwp/

Seasonal Diagnostics Consortium web-page:

http://www.cpc.ncep.noaa.gov/products/people/bjha/

Seasonal Diagnostics Consortium summary paper:

http://www.cpc.ncep.noaa.gov/products/people/bjha/seasonal_diagnostics_consortium.pdf

Table 1: Table 1. Some basic characteristics of the AGCMs used in the attribution effort. Model Type refers to whether quantities are stored and expressed on the basis of spectral wave numbers or by fixed grid point locations. Resolution refers to the spatial scale of the smallest details able to be captured by the model. For spectral models, T stands for "triangular" truncation. For grid point models, resolution indicates how far adjacent grid points are apart from one another. L refers to vertical resolution—specifically, the number of vertical levels in the model. The number of simulations refers to the ensemble size.

Model	**AGCM_1**	**AGCM_2**	**AGCM_3**	**AGCM_4**	**AGCM_5**
Model Type	Spectral	Spectral	Grid Point	Spectral	Grid Point
Horizontal Resolution	T40	T42	2 degr	T40	2 degr lat, 2.5 degr lon
Vertical Resolution	L18	L18	L34	L18	L18
Highest level	2.9 mb	2 mb	2.5 mb	10 mb	3 mb
Number of Simulations	20	18	9	24	10
Total # of Simulations	**81**				

Table 2: Anomaly correlation (AC) between ensemble mean 200-mb height anomalies simulated by five different AGCMs shown in Fig. 4. In each cell number at the top is the spatial anomaly correlation computed over the globe, the number in middle is the AC over the tropical belt, and the number at the bottom is the AC computed over the PNA region.

	AGCM_2	**AGCM_3**	**AGCM_4**	**AGCM_5**
AGCM_1	**0.95** **0.98** **0.85**	**0.97** **0.99** **0.96**	**0.97** **0.99** **0.86**	**0.95** **0.99** **0.90**
AGCM_2		**0.94** **0.99** **0.86**	**0.97** **0.99** **0.96**	**0.97** **0.99** **0.94**
AGCM_3			**0.96** **0.99** **0.86**	**0.95** **0.99** **0.92**
AGCM_4				**0.96** **0.99** **0.92**

References:

Barnston, A. G., A. Kumar, L. Goddard, and M. P. Hoerling, 2004: Improving seasonal predictions practices through attribution of climate variability. *Bull. Ame. Meteor. Soc.*, To appear.